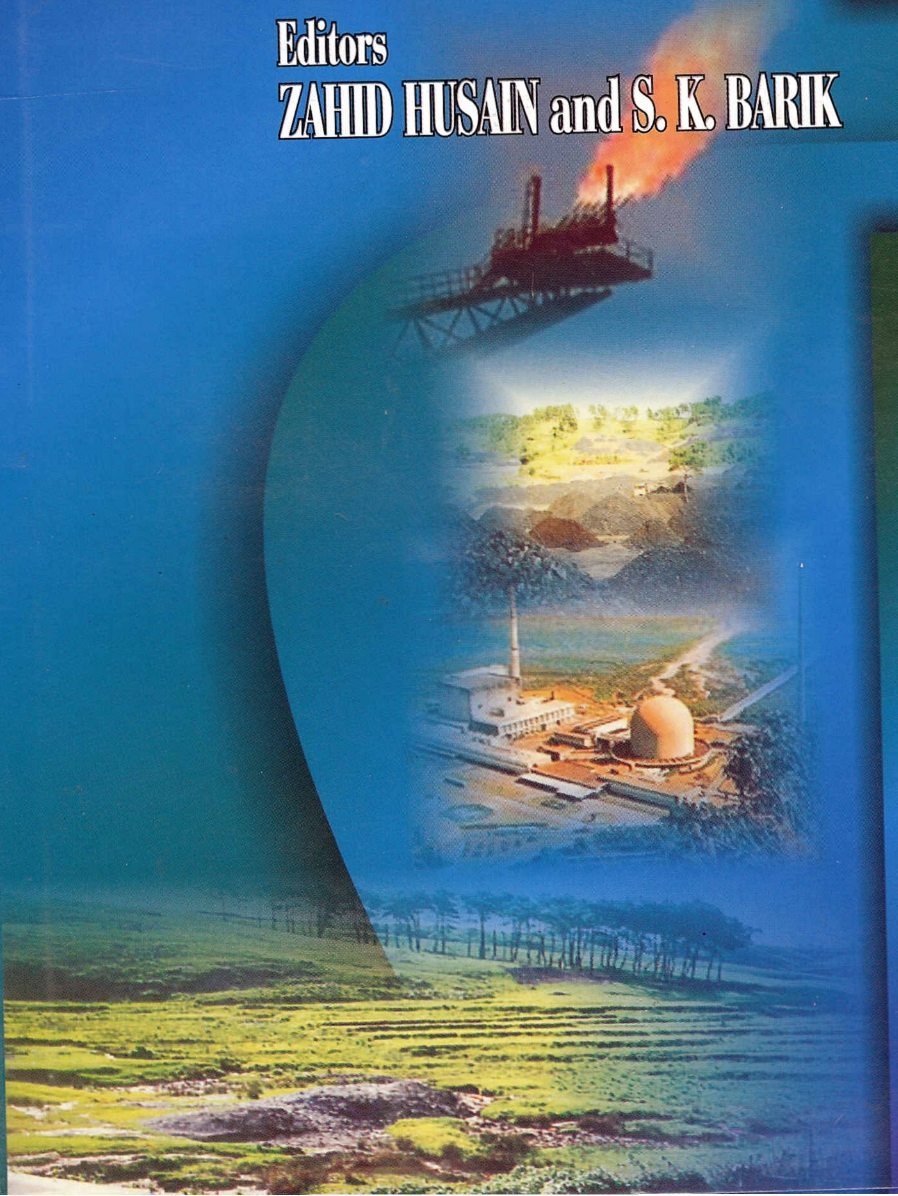
# Development and Environment

Editors

ZAHID HUSAIN and S. K. BARIK



# DEVELOPMENT AND ENVIRONMENT

## DEVELOPMENT OF GEOENERGY RESOURCES AND ITS IMPACT ON ENVIRONMENT AND MAN OF NORTHEAST INDIA

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*Dedicated to*
*Environment and Development*
*of the People*
*of*
*North East India*

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# Preface

North-East India Council for Social Science Research, the premier social science research organization of 30 years standing, held a seminar on Environmental and Sociological Implications of Mining of Coal, Limestone and Uranium and Exploration of Oil and Natural Gas in North East India on 5–6 June 2003. The present volume contains some of the selected papers presented to the seminar. North East India is endowed with huge mineral resources including limestone, coal, natural gas and uranium. Coal is found in all the states of North East India. But except in Assam and Meghalaya coal mining has not been undertaken elsewhere. Mineral resources are largely untapped. In Assam coal mining is done by Coal India Limited. In other states, coal mining is done by private mine owners in most unscientific way causing much environmental hazards, sociological damages and demographical imbalance in the mining areas. Hydrocarbon exploration is mostly done in upper Assam and in adjoining Nagaland and Arunachal Pradesh. Till now maximum petroleum explorations are conducted in the plain areas where geology is favourable. The exploration and exploitation of oil resources should be made in such a way that meet the present need without compromising the needs of the coming generations. Operational activities interact with the environment through long term physical, chemical and biological changes. Pollution control measures should be taken at every stage of exploration and exploitation of hydrocarbon resources of North East India.

Uranium is the basic raw material for the nuclear programme of the country. With the formulation of Atomic Energy Programme in 1948, the search for uranium had commenced. The exploitation of this valuable material is now being carried out by the Uranium Corporation of India Limited (UCIL). The technology adopted by the UCIL is comparable with the best practiced any where in the world. Domiasiat Project in West Khasi Hills district of Meghalaya may bring about a positive development in the social and economic scenario of West Khasi Hills. The project is likely to generate economic opportunities for the people of Meghalaya.The adoption of state of the art technology with environmental monitoring mechanism adopted by the UCIL minimizes health hazards. Nuclear energy will stage as a major source of power which could be made safe and dependable source of energy of the future. But it has to be handled with care by strictly following the International Atomic Energy Agency regulations and as adopted by Atomic Energy Regulatory Board of the country.

We take this opportunity to thank His Excellency the Governor of Meghalaya Mr. M.M. Jacob, Professor G.D. Sharma, Vice-chancellor, Nagaland University, Dr. R. Gupta, Chairman Uranium Corporation of India, Mr. H.K. Mazhari and Dr. S.Q. Hoda, Regional Director, Atomic Minerals Directorate for Exploration and Research who contributed much to the success of the seminar.

We congratulate Dr. Zahid Husain and Dr. S.K. Barik for editing the volume and Regency Publications, New Delhi, for expeditious publication of this volume.

4 June 2004
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B. Datta Ray
Secretary,
North-East India
Council for Social
Science Research

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## PART III: DEVELOPMENT OF HYDROCARBONS AND ITS IMPACT ON ENVIRONMENT AND MAN

# Impact of Coal Mining on the Nokrek Biosphere Reserve of Meghalaya

*K. Sarma, S.K. Barik* and *R.K. Rai*

## Introduction

Mining operations, which involve extraction of minerals from the earth's crust is second only to agriculture as the world's oldest and important activity. In a sense, the history of mining is the history of civilization. Natural resources have been over-exploited for almost two centuries, without any concern for the environment. Mining has resulted in the reduction of forest areas, greater soil erosion, air, water and land pollution, and damage to various species. The unscientific mining of minerals poses a serious threat to the environment. Environmental pollution caused due to mining plays an important role on the productivity of the mine itself. Besides, mining operations seriously affect the environmental health by way of altering the bio-geochemical cycles and polluting the water resources, air and soil. Surface mining of coal causes massive damage to landscape and biological communities (Down and Stocks, 1977). The natural plant communities are disturbed by mining activity and the habitats of the plant communities become impoverished presenting a very rigorous condition for plant growth.

Following coal mining, the physico-chemical properties of soil get altered. Such alterations in soil characteristics influence plant growth and vegetation characteristics. Mined areas suffer from impediments like low organic matter content, nutrient deficiency and moisture retention stress. Mining process inflicts incalculable damage to the land surface irrespective of the mode of extraction employed. High acidity due to oxidation of iron pyrites ($FeS_2$) is an important factor limiting plant growth in the coal-mined areas (Chadwick, 1973; Doubleday, 1974; Caruccio, 1975; Armiger, *et al.*, 1976; Bennet, *et al.*, 1976). High rainfall permits more pyritic oxidation thereby exhibiting excessively acidic soil pH. High acidity in mine spoils causes dysfunction in plant growth, impaired absorption of P, Ca, Mg and K and increased availability of Aluminium (Al), Manganese (Mn), Iron (Fe), Copper (Cu), Zinc (Zn) and Nickel (Ni) often in toxic proportions. The acidity also creates unfavourable biotic conditions such as reduced N-fixation and mycorrhizal activity, and increase in fungal pathogens (Black, 1968; Tucker, *et al.*, 1987).

Paucity of essential plant nutrients particularly nitrogen (Handley *et al.*, 1978, Bradshaw and Chadwick 1980) and phosphorus (Iverson and Wali, 1992) is another factor which limits plant growth in coal mined areas. Nitrogen is essential for plant growth as it is a constituent of all proteins and nucleic acids. It is generally absorbed by the plants as ammonium or as nitrate ions. Lack of mineralisable organic-N and lower mineralisation rate affects the availability of N to plants in coal mined areas (Reeder and Berg, 1977). Phosphorus as Orthophosphate plays a fundamental role in a very large number of enzymatic reactions that depend on phosphorylation. It is essential for cell division and for the development of meristematic tissues. Plants take up phosphorus almost exclusively as inorganic phosphate ions.

The mine spoils present a rigorous habitat, generally characterized by high temperature, moisture stress and surface instability, which favour soil erosion. The steep slopes as well as barren conditions pave the way for low water storage in soil. Evaporation and continuous run-off also result in water loss. Insufficient availability of water for plant growth is also encountered on the mined spoils due to preponderance of sand.



North-East India has large reserves of coal, especially in Assam and Meghalaya. The coal reserves found in this region belong to Gondwana and Tertiary ages. The Gondwana coal deposits are located along the Himalayan foothills from Bhutan Duars to Sadiya. This has not been so far exploited because of the thickness of the seams and transport difficulties. It is the Tertiary coal that is found in thick workable seams and, therefore, mining industry has developed in several places for its extraction. Lower Tertiary deposits are found in Garo Hills, Khasi Hills and Jaintia Hills districts of Meghalaya and Karbi Anglong district of Assam. These deposits were laid down in the Eocene period (Jaintia Group). Middle and Upper Tertiary deposits of coal are found in Ledo-Jaipur-Naginimara area of Assam. These deposits were laid down in the Tikak Parbat Formation of Barail Group during the Oligocene period.

Meghalaya is bestowed with rich natural vegetation and large reserve of mineral resources. During the last few decades, there has been phenomenal increase in mining of coal, limestone and sillimanite causing large scale destructions and deterioration of the natural vegetation of the state. Excessive coal mining operation in many parts of Meghalaya has been responsible for the conversion of original lush green landscape of the area into mine spoils. The primitive and unscientific 'rat-hole' method of mining adopted by private operators had caused ecosystem destruction on an alarming scale. Based on a two-year study, the present paper analyses the impact of coal mining on the flora, vegetation and soil of Nokrek Biosphere Reserve of Meghalaya.

## Study Area

In the western part of Meghalaya, an area of 820 sq. km covering all the three districts of Garo Hills viz., East Garo Hills, West Garo Hills and South Garo Hills has been designated as Nokrek Biosphere Reserve. The Biosphere Reserve is lying between 25°18'39" N to 25°36'7" N latitudes and 90°13'30" E to 91°37'17" E longitudes. The Nokrek Biosphere Reserve is one of the 13 Biosphere Reserves notified in India and one of the 4 Biosphere Reserves from North-East India. The Nokrek Biosphere Reserve was notified on 1st September 1988, which was then only the third Biosphere Reserve in India after Nilgiri

Biosphere Reserve (notified on 1.01.1986) and Nanda Devi Biosphere Reserve (notified on 18.01.1988). The Nokrek Biosphere Reserve is a unique area with a number of rare and endangered plants and animals. The whole buffer area of the Biosphere Reserve is degraded and disturbed due to large-scale coal mining, shifting cultivation and other human activities. Uncontrolled and unscientific mining operation within the Biosphere Reserve has been detrimental to the fragile ecosystems. This has resulted in large-scale degradation of the landscapes, soil, water and forest causing serious threat to the existence of the Biosphere Reserve. In the entire Garo Hills, the total reserve of coal has been estimated to be 359 million tonnes and more than 35 per cent of it is found in West Darrangiri area alone. A considerable portion of this deposit falls under the Nokrek Biosphere Reserve, which lies in the southern and eastern buffer zones of the Biosphere Reserve. Because of complex geological setting, peculiar land holding system and lack of infrastructure, unscientific extraction of coal in unorganised sector within the Biosphere Reserve is going on and the area of coal mining in this region is increasing day by day. Coal mining started within the Biosphere Reserve in the year 1985 at Darrangiri and at present coal is being extracted from 18 coal mining sites.

### Physiography

Nokrek Biosphere Reserve is located in the Tura Range, which is a part of Meghalaya Plateau, having an average altitude of 600 m. The highest point in this region is the Nokrek Peak (1412m) lying within the Biosphere Reserve. The core area of the Biosphere Reserve is Nokrek National Park, which is spread over an area of 47.48 sq. km.

The sources of water for flora and fauna of Nokrek Biosphere Reserve are either by way of rainfall or springs and streams which comprise the perennial drainage system in the Biosphere Reserve. The Tura range is the source of these drainage systems comprising of both north and south flowing rivers. Simsang is the main drainage system of the Biosphere Reserve which originates near Nokrek peak. From the source, it flows directly north and takes an eastward turn from where it forms the northern boundary of the Biosphere Reserve. The main tributaries of Simsang River,



which drain the Biosphere Reserve, are Rongrim, Khamphil, Rongre, Chibok, Rongon, and Chibe. The other north flowing main drainage systems are Mandal, Ganol, Selbel and Ronkhen. The main south flowing rivers which ultimately flow to Bangladesh are Ronkho, Rongshi, Noreng, Wagechi, Dareng, Bugi, Rongme, Ginura, Daji, Mindri, Jetra, Rongasi, Thokong, Rongma, Rongdik and Rinang.

### Soil

The soil of most part of the Biosphere Reserve is red loam. The soil is poor in silica but rich in clay forming materials. The soil is generally loamy but often found clayey to sandy loam. The surface horizon which is about 30 cm thick has colours ranging from reddish brown to dark reddish brown. The soils are rich in organic matter and nitrogen but deficient in phosphorous and potassium. The soil of the Biosphere Reserve is acidic in reaction.

### Climate

The general climate of the study area is monsoon type and is directly influenced by the south-west monsoon. Based on the climatic conditions the year may be divided into summer, rainy, autumn and winter seasons. The summer season (April to mid May) is characterized by relatively high temperature, occasional thunderstorms and high velocity wind. In this season, the average maximum temperature goes up to 30.7°C. The rainy season commences with the onset of south-west monsoon in mid May and lasts up to September. This is the wettest period of the year and about three fourth of the annual rainfall is received during this period. The air temperature is close to that of the summer season. The rainy season is followed by a brief autumn during October and November. The sharp decline in rainfall and lowering of temperature are the characteristic features of this season. It is a transitory period between rainy and winter seasons. The winter season extends from December to March. It is the coldest period of the year. Morning fog and dry weather are the characteristic features of this season. A few intermittent light showers are also received during this period. The mean temperature goes down to 7.5°C during mid winter i.e., December/January. The area receives the mean annual rainfall of 2400 mm.

## Vegetation

The vegetation of Nokrek Biosphere Reserve can be broadly classified into tropical and subtropical types depending on the altitude. The tropical vegetation are found upto an elevation of about 1000m. It includes evergreen, semievergreen and moist deciduous forests, bamboo brakes, grasslands, riverine forests and swamps. The forests could be distinguished into three distinct vertical layers viz., tree, shrub and herb. The trees in the upper canopy includes *Aesculus assamica, Aporusa wallichii, Bridelia retusa, Butea monosperma, Castonopsis armata, Cryptocarya andersonii, Dillenia indica, Dillenia pentagyna, Ficus* spp. *Gmelina arborea, Grewia* spp., *Gymnosporia salicifolia, Hovenia acerba, Largerstroemia parviflora, Leea macrophylla, Munronia pinnata, Pilioatigma malabaricum, Schima wallichii, Schleichera trijuga, Shorea robusta, Syzygium kurzii, Talauma hodgsonii, Terminalia belerica, Terminalia chebula, Toona ciliata,* and *Vitex pedunchrularis. Engelhardtia spicata, Ficus prostrata, Helicia robusta, Hibiscus macrocarpus, Miliusa velutina* and *Zizyphus rugosa* form the lower canopy of the forest. The main shrub species are: *Acacia concinna, Bauhinia acuminata, Capparis zeylanica, Eupatorium adinoforum, Garcinnia lancifolia, Mimosa himalayayana* and *Mussaendra roxburghii*. Several species of bamboo form thickets of secondary vegetation, which cover substantial area of the Biosphere Reserve. The ground flora in deciduous forests is generally poor. In evergreen forests, species of *Alpinia, Amomum, Colocasia,* and *Hedychium* dominate the ground flora. The epiphytic climbers such as *Rhaphidophora* spp., *Hoya* spp. and many stem parasites are seen in these forests. A few species of epiphytic orchids viz., *Aeridis, Bulbophyllum, Dendrobium, Eria, Liparis, Photidota, Thunia* and *Vanda* are seen in the evergreen forests. The herbaceous vegetation is less profuse and includes the members of Oxlidaceae, Balsaminanceae, Acanthaceae, Leeaceae, Fabaceae, Asteraceae and Poaceae. Besides, *Sida* spp. and *Leea* spp., *Coffea bengalensis, Impereta cylindrical* and *Chromolaena odorata* are also prominent.



The subtropical vegetation occurs at elevations beyond 1200 m above sea level. This type of forest is restricted to the Tura peak and Nokrek peak only. These are mainly evergreen forests but a few elements of deciduous forest are also seen. The upper canopy is composed of species like *Castanopsis hystrix, Betula culindristachus, Kevia floribunda, tamula phellocarna, Dryntes lancifolia, Ficus* spp., *Vitex altissima, Adina cardifolia* and *Sterculia villosa*. Species such as *Persea gamblei, Persea villosa, Carnicia paniculata, Eriobotrya bengalensis, Quercus semiserrata* and *Litsea* spp. form the middle canopy of the forest. The lower canopy comprises of *Aglata roxburghii, Mitrephora tomentosa, Premna multifolia, Litsea* spp. and *Ficus* spp. The shrub layer is dominated by *Munronia pinnata, Eriobotrya angustissima, Antistriphe oxyantha, Strobilanthes glomeratus and Erianthus* spp.

## Methods

### *Vegetation*

For the study of community characteristics of the Nokrek Biosphere Reserve vegetation in unmined and mined areas three coal mining sites were selected viz., Budugiri, Budu Wathegiri and Faraamgiri. For tree components, 10 quadrates of 10m × 10m size each were laid randomly in the unmined and mined areas at each site. For shrub species, 10 quadrates of 5m × 5m size each in mined and unmined areas were laid. The herb species were studied by laying 40 quadrates each of 1m × 1m size in mined and unmined areas. The species found in quadrates were identified with the help of the herbaria of Botany Department, North-Eastern Hill University and Botanical Survey of India, North-Eastern Circle, Shillong.

Quantitative community characteristics such as frequency, density, basal area and importance value index (IVI) of each component were determined by following the methods as outlined by Mishra (1968) and Muller-Dombois and Ellenberg (1974).

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats of occurrence of a species}}{\text{Total number of quadrates studied}} \times 100$$

$$\text{Density} = \frac{\text{Total number of individuals of a species}}{\text{Total number of quadrates studied}}$$

Basal cover = Density × average basal area of individuals of a species

Basal area was calculated for herbs and shrubs based on the measurement of stem diameter at basal level and for trees CBH at 1.37 m height.

$$\text{Abundance} = \frac{\text{Number of individuals of a species}}{\text{Number of quadrates of occurrences of the species}}$$

The distribution pattern of the species in the forests were studied by Whitford's index (Whitford 1948).

$$\text{Whitford's index} = \frac{\text{Abundance (A)}}{\text{Frequency (F)}}$$

If A/F ratio: <0.025 -Regular distribution
0.025-0.05 -Random distribution
>0.05 -Contagious or clumped distribution

Shannon's index of General Diversity was calculated by using the formula

$$H = -\Sigma\,(n_i / N)\ln(n_i / N)$$

Where, H = Shannon's index of general diversity
$n_i$ = importance value index of a species
N = total importance values of all species

**Soil**

Three composite soil samples were collected both from mined and adjacent unmined areas. Soil samples from three depths *viz.*, 0–10 cm, 10–20 cm and 20–30 cm during three seasons, i.e., pre-monsoon, monsoon and post-monsoon were collected. The study was conducted for two years period i.e., during 2000 and 2002. Thus in total 54 soil samples for each season and each year were collected. The soil samples were air dried and sieved through 0.2 mm sieve and stored for analysis.

A digital pH meter was used to determine soil pH in 1:2.5 suspension of soil and distilled water (Anderson and Ingram 1993). Soil moisture content was gravimetrically determined by drying 10 gm of freshly sieved soil at 105°C for 24 hours in a hot air oven (Allen *et al.*, 1974). Soil texture was analysed by Bouyoucos hydrometer method (Allen *et al.*, 1974). Air-dried and sieved (0.5 mm) soils were used for total Kjeldahl nitrogen (TKN), and available-P. TKN was determined by digesting the soil sample with concentrated $H_2SO_4$ using Kjeltab as catalyst in a block digester. Soil organic carbon was determined by rapid titration method (Walkley and Black, 1934) and soil organic matter was estimated by multiplying the organic carbon content by 1.724 assuming that soil organic carbon contains 58% carbon (Allen *et al.*, 1974). Available phosphorus was determined by molybdenum blue method after extracting the soil P in 0.5 M sodium bicarbonate solution (Anderson and Ingram, 1993).



Analysis of Variance (ANOVA) was performed on the data to test the variability due to site, mining activity and depth. 3-way fixed effect ANOVA model was used for analysis (Zar, 1974).

**Results and Discussion**

***Floristic Composition***

The total number of plant species found in the mined areas was significantly less than the unmined areas. The number of tree species was higher in the unmined areas (31–44) than the mined areas (25–26). With the exception of herb species at Budugiri site, the tree and shrub species showed a drastic reduction in their number due to mining. The number of shrub species was much less in comparison to tree and herbs at all the three sites (Table 1). Fifteen tree species, 4 shrub and 28 herb species were exclusively found in mined sites, while 27 tree species, 4 shrub species and 16 herb species were exclusively found in the unmined sites (Table 2).

Since the mined and unmined areas had similar climatic, edaphic and physiographic features the differences in species composition could be attributed to the mining activities. This is in agreement with the findings of Das Gupta (1999), Baig (1992), Jha and Singh (1990). Leisman (1957) and Gibson *et al.* (1985) stressed the importance of surrounding vegetation and the dissemination efficiency of propagules in spoil seed banks for rapid colonization of mined areas. Bradshaw and Chadwick (1980) working on the colliery spoils reported that the number of species colonizing on spoil was influenced by its pH. Decline in pH in mine spoils is one of the serious problems associated with coal

**Table 1. Species Composition in Unmined and Mined Areas at Three Sites in Nokrek Biosphere Reserve**

| Species Composition | Budugiri | | Budu Wathegiri | | Faramgiri | |
|---|---|---|---|---|---|---|
| | Unmined | Mined | Unmined | Mined | Unmined | Mined |
| **Tree** | | | | | | |
| Number of species | 38 | 25 | 31 | 26 | 44 | 25 |
| Number of genera | 35 | 24 | 29 | 26 | 36 | 20 |
| Number of families | 26 | 20 | 20 | 19 | 28 | 16 |
| **Shrub** | | | | | | |
| Number of species | 5 | 6 | 16 | 13 | 18 | 17 |
| Number of genera | 5 | 5 | 15 | 12 | 16 | 17 |
| Number of families | 5 | 5 | 14 | 12 | 14 | 14 |
| **Herb** | | | | | | |
| Number of species | 28 | 33 | 26 | 17 | 18 | 18 |
| Number of genera | 26 | 31 | 26 | 16 | 17 | 18 |
| Number of families | 23 | 26 | 22 | 10 | 16 | 15 |

**Table 2. Plant Species Found Exclusively in Unmined and Mined Areas of the Nokrek Biosphere Reserve**

| Unmined | Mined |
|---|---|
| **Tree species** | |
| *Antidesma acuminatum* Wall. Ex Wt | *Alchornea tiliaefolia* Muell.-Arg. |
| *Artemisia nilagirica* (Clarke.) Pamp. | *Anacardium occidentale* linn. |
| *Casearia kurzii* Cl. | *Bauhinia variegata* Linn. |
| *Citrus medica* Linn. | *Bridelia monoica* (Lour.) Merr. |
| *Clausena heptaphylla* (Roxb.) W. and A. | *Callicarpa arborea* Roxb. |
| *Cleidion spiciflorum* (Burm.) Merr. | *Cordia grandis* Roxb. |
| *Daphne composita* (L.f.) Gilg | *Duabanga grandiflora* (Roxb.ex.DC.) Walp |
| *Dysoxylum gobara* (Buch.-Ham.) Merr. | *Erythrina stricta* Roxb. |
| *Ficus gasparriniana* Miq. | *Euonymus attenuatus* Laws. |
| *Garcinia paniculata* (G. Don.) Roxb. | *Meliosma wallichii* Planch. ex. Hk.f. |
| *Helicia nilagirica* Bedd. | *Prunus cerasoides* D. Don |
| *Homonia riparia* Lour. | *Saurauia nepaulensis* DC. |
| *Kydia calycina* Roxb. | *Schima wallichii* (DC.) Korth. |
| *Litsea cubeba* Lour. | *Spondias pinnata* (Linn.f) Kurze. |
| *Litsea salicifolia* (Roxb. Ex Nees) Hk.f. | *Writhtia coccinea* Roxb. |
| *Maesa indica* (Roxb.) Wall. | |
| *Melodinus khasianas* Hk.f. | |
| *Ostodes paniculata* Bl. | |

contd. ...



*Table 2... contd.*

| Unmined | Mined |
|---|---|
| *Picrasma javanica* Bl. | |
| *Rhus javanica* Linn. | |
| *Saprosma ternatum* Hk.f. | |
| *Skimmia laureola* (DC.) Sieb ex Walp. | |
| *Sterculia hamiltonii* (O) Ktze. | |
| *Syzygium cumini* (Linn.) Skeels | |
| *Terminalia bellerica* (Gaertn) Roxb. | |
| *Tetrameles nudiflora* R. Br. | |
| *Zizyphus mauritiana* Lamk. | |
| **Shrub species** | |
| *Ardisia odontophylla* DC | *Agapetes variegata* Roxb. |
| *Calophyllum polyanthum* Choisy | *Clerodendrum viscosum* Vent. |
| *Psychotria erratica* Hk.f. | *Clerodendrum wallichii* Merr. |
| *Rubus ellipticus* Sm. | *Elscholtzia blanda* Benth. |
| **Herb species** | |
| *Arisaema tortuosum* (Wall.) Schott. | *Agapetes variegata* Roxb. |
| *Cynotis vaga* Lour. | *Cyperus compressus* Linn. |
| *Dischidia nummularia* R.Br. | *Desmodium racemosa* (Thunb.) DC. |
| *Elatostemma rupestre* (D. Don) Wedd. | *Digitaria ciliaris* (Reitz.) Koel. |
| *Erythroxylum kunthianum* Wall. ex Kurz. | *Embelia ribes* Burn. F |
| *Hoya lanceolata* Wall ex D. Don. | *Eupatorium adenophorum* Spreng. |
| *Marchantia* sp. | *Eupatorium odoratum* Linn. |
| *Molineria capitulata* Lour. | *Hedyotis scandence* D. Don. |
| *Olax acuminata* Wall. | *Ipomea simosa* |
| *Piper longum* Linn. | *Jasminium lanceolarum* Roxb. |
| *Pogestemon auricularis* Hask. | *Leea crispa* Linn. |
| *Psychotria erratica* Hk.f. | *Morinda angustifolia* Roxb. |
| *Smilax ferox* Kunth | *Murrya paniculata* Linn. |
| *Strobilanthus discolor* Nees. | *Ophiopogon parviflorus* (Hook) f. Hara. |
| *Tacca laevis* Roxb. | *Oxalis* sp. |
| *Vandelia multiflora* (Roxb) D. Don. | *Phyllanthus raticulatus* Poir. |
| | *Piper thomsonii* Hk.f. |
| | *Plantago major* Hook.f. |
| | *Plectranthus ternifolius* D. Don |
| | *Sapondus pinnata* (Linn.f.) Kurz. |
| | *Selinum striatum* Cl. |
| | *Senecio griffithii* Clarke. |
| | *Senecio scandens* Buch.-Ham.ex D. Don |
| | *Solanum tora* |
| | *Stephania japonica* (Thunb.) Miers. |
| | *Thysanolaena maxima* (Roxb.) O. Ktze. |
| | *Triumfetta tomentosa* Bojer |
| | *Zanthoxylum armatum* Hk.F. |

mining activity. Lowering of pH strongly affects the plant growth in various ways including the availability of a large number of essential nutrients in the soil.

## Community Characteristics

### *Density*

The total plant density in mined areas ranged between 3250 and 4161 stems per ha while that in the unmined areas ranged between 6720 and 7260 stems $ha^{-1}$. The density of trees, shrubs and herbs in mined areas were significantly lower than the unmined areas at all the three sites (Fig. 2).

The unmined areas had greater plant diversity compared to the mined stands because of acidic pH, moisture stress and nutrient property of the latter. Lyngdoh (1995) and Das Gupta's (1999) works lend support to the present findings.

## Dominance Pattern

The dominance was different for tree, shrub and herb components. The dominance was concentrated in one or two species in case of shrub and herb, while in case of trees, dominance was distributed more or less evenly among many species.The dominant species in mined and unmined areas even at the same site were also different except that in Faramgiri, where *Ficus racemosa* was the dominant tree species both in mined and unmined areas. The dominant tree species in the unmined areas at three sites was also different. At Budugiri, *Kydia calycina* and *Dysoxylum gobara* were dominant and codominant, while at Budu Wathegiri, *Ostodes paniculata* and *Persea duthei* were dominant and codominant, respectively. However, in mined areas there was some similarity in dominant species composition. At Budugiri mined areas *Bridelia monoica* was the dominant tree species. *Schima wallichii, Bauhinia variegata* and *Spondias pinnata* were codominant species. *Ficus hispida* was dominant at Faramgiri mined site. *Ficus racemosa, Meliotus wallichii* and *Schima wallichii* were codominance at this site. *Schima wallichii* and *Spondius pinnata* were dominant in mined sites at Budu Wathegiri while *Ficus hispida* and *Meliotus wallichii* were codominance at this site.



The common important tree species found at all the three mined sites were, *Schima wallichii, Spondius pinnata, Bauhinia variegata, Ficus hispida* and *Meliotus wallichii*. The common important tree species in the unmined sites were *Dysoxylum gobara, Ostodes paniculata* and *Macropanax undulatus*. *Citrus* sp. *Hiptage benghalensis, Clerodendrum wallichii, Elsholtzia blanda, Psychotria erratica* were the dominant shrub species in the unmined areas while in the mined areas *Clerodendrum wallichii, Agapetes variegata, Millitia pachycarpa, Desmodium racemosa, Lantana camara, Olea dentana* were dominant. Among the herb species *Davallia* sp. *Piper longrum, Asplenium* sp. were the dominant in unmined areas while in the mined areas *Eupatorium adenophorum, Pteris* sp., *Thysanolaena maxima, Asplenium* sp., *Eleusine corocana* and *Inula cappa* were dominant species.

## Species Diversity

Shannon's diversity index for tree species was low in the mined sites than the unmined sites both at Budugiri and Faramgiri, indicating the adverse impact of mining on tree diversity (Table 3). However, at Budu Wathegiri, the trend was reverse. This could be attributed to the existence of bigger trees and causing less damage to the trees during mining operation by the miners. The diversity index for herbs increased with mining suggesting that mining operation enhanced the colonization of certain species in the newly created habitats due to mining.

## Impact of Mining on Distribution Pattern

Plant populations exhibit three patterns of spatial distribution — contagious or clumped, random and uniform or regular. Patchiness, or the degree to which individuals are aggregated or

**Table 3. Shannon's Species Diversity Index in Unmined and Mined Areas of Nokrek Biosphere Reserve**

| *Plants* | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | |
|---|---|---|---|---|---|---|
| | *Mined* | *Unmined* | *Mined* | *Unmined* | *Mined* | *Unmined* |
| Tree | 2.97 | 3.42 | 4.30 | 3.33 | 3.13 | 3.60 |
| Shrub | 1.75 | 1.34 | 2.39 | 2.33 | 2.65 | 2.74 |
| Herb | 2.37 | 2.25 | 2.65 | 2.25 | 2.62 | 2.01 |

**Table 4. Proportion (%) of Tree Species Under Different Distribution Pattern in the Unmined and Mined Areas of Nokrek Biosphere Reserve**

| Distribution Pattern | Budugiri Unmined | Budugiri Mined | Budu Wathegiri Unmined | Budu Wathegiri Mined | Faramgiri Unmined | Faramgiri Mined |
|---|---|---|---|---|---|---|
| Regular | 0 | 0 | 0 | 0 | 2.3 | 0 |
| Random | 10.5 | 4.2 | 37.5 | 11.5 | 11.4 | 0 |
| Contagious | 89.5 | 95.8 | 62.5 | 88.5 | 86.3 | 100 |

dispersed, is crucial to the understanding of how species uses resources, and how it is used as a resource. Besides, the distribution pattern of species population is often related to its reproductive biology. Webb *et al.* (1967), Ashton (1972) and Austin *et al.* (1972) indicated that in the absence of major disturbance, soil and water conditions play major role in controlling species distribution pattern.

Most tree species showed contagious distribution pattern both in the unmined (89.5%, 62.5% and 86.3%) and mined (95.8%, 88.5% and 100%) areas at Budugiri, Budu Wathegiri and Faramgiri, respectively (Table 4).

The contagious distribution pattern for most tree species indicated the mosaicness of the forest stands. The increase in contagiousness of more species due to mining suggests the increase in patchness of the natural vegetation due to mining.

## Impact of Coal Mining on Soil Characteristics

*pH*: The soil pH in the unmined areas ranged between 5.89–6.64. The soil became more acidic in mined areas. In the mined areas it ranged between 4.02 and 5.93 and in the unmined areas it varied between 5.89 and 6.64 (Table 5). The soil pH was significantly ($P<0.01$) lower in all the mining sites than the unmined sites in all the seasons and across all the depths. The post-monsoon soil pH was significantly lower ($P<0.01$) than the pre-monsoon and monsoon soil pH. The top layers of soils (0–10 cm) had significantly lower soil pH than the sub-soils (10–20 and 20–30 cm) (Table 6).

*Soil Moisture Content*: The soil moisture content significantly reduced as depth increased ($P<0.05$). In the mined areas the soil moisture ranged between 4.96% and 13.49%. The minimum



**Table 5. Soil pH in the Unmined and Mined Areas in Different Depths and Seasons in the Nokrek Biosphere Reserve**

| Depth (cm) | Pre-monsoon | | | | | | Monsoon | | | | | | Post-monsoon | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Budugiri | | Budu Wathegiri | | Faramgiri | | Budugiri | | Budu Wathegiri | | Faramgiri | | Budugiri | | Budu Wathegiri | | Faramgiri | |
| | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M |
| 0–10 | 6.35 ± 0.07 | 4.65 ± 0.13 | 6.64 ± 0.20 | 4.45 ± 0.10 | 6.22 ± 0.16 | 4.64 ± 0.09 | 6.34 ± 0.19 | 5.60 ± 0.29 | 6.51 ± 0.18 | 5.82 ± 0.17 | 6.37 ± 0.29 | 5.53 ± 0.30 | 5.99 ± 0.20 | 4.51 ± 0.10 | 6.13 ± 0.16 | 4.02 ± 0.10 | 5.89 ± 0.07 | 4.24 ± 0.16 |
| 10–20 | 6.32 ± 0.12 | 5.58 ± 0.04 | 6.36 ± 0.23 | 5.41 ± 0.22 | 6.54 ± 0.24 | 5.54 ± 0.21 | 6.43 ± 0.19 | 5.82 ± 0.15 | 6.37 ± 0.19 | 5.46 ± 0.14 | 6.64 ± 0.20 | 5.63 ± 0.10 | 6.26 ± 0.07 | 4.11 ± 0.23 | 6.09 ± 0.09 | 4.28 ± 0.27 | 6.32 ± 0.16 | 4.09 ± 0.27 |
| 20–30 | 6.39 ± 0.18 | 5.4 ± 0.21 | 6.11 ± 0.17 | 5.41 ± 0.21 | 6.01 ± 0.13 | 5.34 ± 0.21 | 6.37 ± 0.18 | 5.93 ± 0.21 | 6.49 ± 0.29 | 5.68 ± 0.17 | 6.51 ± 0.32 | 5.73 ± 0.10 | 5.90 ± 0.13 | 5.19 ± 0.11 | 5.99 ± 0.28 | 4.97 ± 0.12 | 6.17 ± 0.28 | 5.27 ± 0.16 |

**Table 6. Results of Analysis of Variance (ANOVA) to Test the Variability in Soil pH due to Mining Activity, Site and Depth**

| *Source of Variation* | *Degree of freedom* | *Sum of squares* | *Mean sum of squares* | *F ratio* |
|---|---|---|---|---|
| General Mean | 1 | 1756.93 | 1756.97 | – |
| Mining effects | 1 | 18.28 | 18.28 | 881.82** |
| Site effects | 2 | 0.71 | 0.35 | 17.08** |
| Depth effects | 2 | 5.34 | 2.67 | 128.74** |
| Mining-Site | 2 | 1.06 | 0.53 | 25.65** |
| Mining – Depth | 2 | 1.45 | 0.73 | 35.03** |
| Site-Depth | 4 | 0.70 | 0.17 | 8.39** |
| Mining-Site-Depth | 4 | 1.07 | 0.27 | 12.89** |
| Residual | 36 | 0.75 | 0.02 | – |
| Total | 54 | 1786.32 | 33.08 | – |

percentage of soil moisture in the unmined areas was 26.27 while maximum was 42.62% (Table 7). The soil moisture content, however, did not vary significantly due to mining activities and site differences (Table 8).

*Soil Texture*: The percentage of sand in the soil was much higher in the unmined areas than the mined areas. In the mined areas soil texture is sandy loam and had more clay contents than the unmined areas (Table 9).

*Nitrogen (%)*: The coal mining had significant impact on soil nitrogen content. Due to mining, the total nitrogen content was significantly ($P<0.01$) reduced. In the unmined sites, total soil nitrogen ranged between 0.27% and 0.74% while it was reduced to 0.02% to 0.44% in the mined sites (Table 10). The nitrogen content was also significantly lower ($P<0.01$) in the deep soils than the top soils (Table 11).

*Phosphorus*: The phosphorus concentration in the mined areas varied between 8.0 and 21.67%, while in the unmined areas it ranged between 16.0 and 24.6% (Table 12). However, the mining did not have a significant impact on the phosphorus content of the soil (Table 13).

*Soil Organic Matter and Carbon*: The percentage of soil organic matter and carbon drastically reduced due to mining. (Table 14 and Table 16). The soil organic matter and carbon decreased significantly with increasing depths ($P<0.01$). The soil



**Table 7. Soil Moisture Content in the Unmined and Mined Areas in Different Depths and Seasons in the Nokrek Biosphere Reserve**

| Depth (cm) | Pre-monsoon | | | | | | Monsoon | | | | | | Post-monsoon | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Budugiri | | Budu Wathegiri | | Faramgiri | | Budugiri | | Budu Wathegiri | | Faramgiri | | Budugiri | | Budu Wathegiri | | Faramgiri | |
| | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M |
| 0–10 | 31.24 ± 1.65 | 5.31 ± 0.46 | 26.27 ± 4.45 | 5.05 ± 0.59 | 32.32 ± 3.22 | 5.99 ± 0.68 | 40.48 ± 2.81 | 12.99 ± 0.58 | 38.84 ± 1.58 | 12.5 ± 0.63 | 39.14 ± 2.31 | 13.49 ± 0.89 | 29.41 ± 1.49 | 9.10 ± 0.51 | 27.24 ± 1.09 | 6.42 ± 0.72 | 29.24 ± 1.45 | 5.54 ± 0.61 |
| 10–20 | 32.91 ± 2.02 | 5.02 ± 0.39 | 30.00 ± 3.66 | 5.13 ± 0.27 | 30.42 ± 3.88 | 5.31 ± 0.33 | 39.78 ± 1.57 | 9.83 ± 0.39 | 41.68 ± 1.45 | 9.97 ± 0.71 | 42.62 ± 1.34 | 10.04 ± 0.67 | 28.54 ± 1.01 | 6.12 ± 0.54 | 28.91 ± 0.99 | 6.12 ± 0.66 | 28.13 ± 0.96 | 6.06 ± 0.54 |
| 20–30 | 35.83 ± 1.83 | 5.55 ± 0.42 | 31.21 ± 2.52 | 4.96 ± 0.40 | 37.67 ± 2.17 | 6.20 ± 0.75 | 38.05 ± 2.54 | 9.10 ± 0.91 | 35.40 ± 1.87 | 9.56 ± 0.98 | 39.59 ± 2.24 | 9.22 ± 1.08 | 27.42 ± 1.52 | 6.54 ± 0.50 | 26.84 ± 1.46 | 9.29 ± 0.46 | 26.42 ± 1.46 | 6.47 ± 0.52 |

**Table 8. Results of Analysis of Variance (ANOVA) to Test the Variability in Soil Moisture Content due to Activity, Site and Depth**

| *Source of Variation* | *Degree of freedom* | *Sum of squares* | *Mean sum of squares* | *F ratio* |
|---|---|---|---|---|
| General Mean | 1 | 60799.98 | 60799.98 | – |
| Mining effects | 1 | 3.62 | 3.62 | 0.08 |
| Site effects | 2 | 180.10 | 90.06 | 2.07 |
| Depth effects | 2 | 298.21 | 149.11 | 3.42* |
| Mining-Site | 2 | 955.26 | 477.63 | 10.95** |
| Mining-Depth | 2 | 332.41 | 166.21 | 3.81* |
| Site-Depth | 4 | 210.03 | 52.51 | 1.20 |
| Mining-Site-Depth | 4 | 438.61 | 109.65 | 2.51 |
| Residual | 36 | 1569.71 | 43.60 | – |
| Total | 54 | 64787.95 | 1199.78 | – |

**Table 9. Soil Texture in the Unmined and Mined Areas in Different Depths and Seasons in the Nokrek Biosphere Reserve**

| *Site:* | *Depth (cm)* | *Clay (%)* | *Silt (%)* | *Sand (%)* | *Textural Class* |
|---|---|---|---|---|---|
| Unmined | 0–10 | 1.69 ± 0.16 | 4.88 ± 0.18 | 93.23 ± 0.21 | Sandy |
| | 10–20 | 1.57 ± 0.18 | 5.06 ± 0.19 | 93.08 ± 0.32 | Sandy |
| | 20–30 | 1.35 ± 0.04 | 4.97 ± 0.28 | 93.67 ± 0.31 | Sandy |
| Mined | 0–10 | 9.52 ± 0.18 | 4.79 ± 0.17 | 85.70 ± 0.24 | Sandy loam |
| | 10–20 | 8.81 ± 0.38 | 4.76 ± 0.33 | 86.43 ± 0.62 | Sandy loam |
| | 20–30 | 8.71 ± 0.28 | 4.42 ± 0.26 | 86.87 ± 0.36 | Sandy loam |

organic carbon content also varied significantly ($P<0.05$) among different sites and seasons studied (Table 15 and Table 17).

*C/N Ratio*: The C/N ratio varied significantly ($P<0.01$) among different sites. However, it did not vary due to mining activity. In the mined areas it ranged between 3.27 and 10.23 and in the unmined areas it ranged between 2.33 and 19.11 (Table 18 and Table 19).

## Discussion

Due to extensive coal mining, large areas of Nokrek Biosphere Reserve have been turned into degraded land, creating unfavourable habitat conditions for plant growth. Mining of coal caused massive damage to landscape and biological communities. It was found that the number of tree species got reduced due to



**Table 10. Percentage of Nitrogen Content in the Unmined and Mined Areas in Different Depths and Seasons in the Nokrek Biosphere Reserve**

| *Depth (cm)* | *Pre-monsoon* | | | | | | *Monsoon* | | | | | | *Post-monsoon* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | |
| | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* |
| 0–10 | 0.38 ± 0.01 | 0.12 ± 0.01 | 0.37 ± 0.03 | 0.10 ± 0.01 | 0.39 ± 0.04 | 0.14 ± 0.03 | 0.74 ± 0.01 | 0.04 ± 0.01 | 0.63 ± 0.03 | 0.04 ± 0.01 | 0.71 ± 0.02 | 0.04 ± 0.01 | 0.63 ± 0.03 | 0.12 ± 0.01 | 0.61 ± 0.03 | 0.15 ± 0.05 | 0.61 ± 0.02 | 0.23 ± 0.11 |
| 10–20 | 0.31 ± 0.03 | 0.11 ± 0.01 | 0.32 ± 0.06 | 0.11 ± 0.01 | 0.27 ± 0.04 | 0.12 ± 0.01 | 0.59 ± 0.01 | 0.13 ± 0.02 | 0.61 ± 0.02 | 0.13 ± 0.02 | 0.59 ± 0.02 | 0.09 ± 0.02 | 0.56 ± 0.04 | 0.20 ± 0.01 | 0.56 ± 0.03 | 0.23 ± 0.10 | 0.57 ± 0.03 | 0.27 ± 0.13 |
| 20–30 | 0.38 ± 0.03 | 0.11 ± 0.01 | 0.41 ± 0.04 | 0.02 ± 0.01 | 0.32 ± 0.04 | 0.11 ± 0.01 | 0.65 ± 0.03 | 0.13 ± 0.01 | 0.61 ± 0.02 | 0.44 ± 0.24 | 0.61 ± 0.02 | 0.13 ± 0.01 | 0.58 ± 0.04 | 0.10 ± 0.01 | 0.57 ± 0.04 | 0.10 ± 0.01 | 0.62 ± 0.03 | 0.1 ± 0.01 |

**Table 11. Results of Analysis of Variance (ANOVA) to Test the Variability in Percentage Nitrogen Content due to Mining Activity, Site and Depth**

| *Source of Variation* | *Degree of freedom* | *Sum of squares* | *Mean sum of squares* | *F ratio* |
|---|---|---|---|---|
| General Mean | 1 | 5.87 | 5.87 | – |
| Mining effects | 1 | 2.08 | 2.08 | 781.50** |
| Site effects | 2 | 0.00 | 0.00 | 0.45 |
| Depth effects | 2 | 0.28 | 0.14 | 53.52** |
| Mining-Site | 2 | 0.30 | 0.02 | 6.33** |
| Mining – Depth | 2 | 0.16 | 0.08 | 30.34** |
| Site-Depth | 4 | 0.03 | 0.10 | 2.96** |
| Mining-Site-Depth | 4 | 0.05 | 0.10 | 4.65** |
| Residual | 36 | 0.10 | 0.00 | – |
| Total | 54 | 8.61 | 0.16 | – |

mining. The unfavourable habitat conditions prevailing in the coal mined areas might have reduced the regeneration of many tree species, thereby reducing the number of tree species in the mined areas. Similar observations were made in the studies conducted in the coal mining areas in different parts of the world (Cornwell 1971, Fyles *et al.*, 1985; Game *et al.*, 1982; Singh and Jha, 1987; Jha and Singh, 1990). The number of shrub species recorded was much less in comparison to trees and herbs. Although the number of tree and shrub species was reduced due to mining, the number of herb species colonizing the mined areas was found higher than the unmined sites. This could be due to the better ability of herbaceous species to adapt to the disturbed habitats. Besides, certain herb species invaded the newly created habitats due to mining. Fifteen among tree, 4 among shrub and 28 among herb species were found only in mined sites, while 27 tree species, 4 shrub species and 16 herb species were found exclusively in the unmined sites. The density of trees, shrubs and herbs also got reduced due to mining. The works of Lyngdoh (1995) and Das Gupta (1999) in Jaintia Hills coal fields of Meghalaya had more or less similar observations. The dominance was shared by many species both at mined and unmined areas. In unmined sites, *Castanopsis kurzii, Ficus racemosa, Ostodes paniculata, Dysoxylum gobara, Caryota urens, Persea duthei* and *Macropanax undulatus* were dominant tree species, while *Bridelia monoica, Schima wallichii, Ficus hispida, Spondias pinnata, Meliosma*



**Table 12. Phosphorus Content in the Unmined and Mined Areas in Different Depths and Seasons in the Nokrek Biosphere Reserve**

| *Depth (cm)* | *Pre-monsoon* | | | | | | *Monsoon* | | | | | | *Post-monsoon* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | |
| | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* |
| 0–10 | 19.56 ± 2.32 | 16.33 ± 1.57 | 20.4 ± 1.71 | 16.8 ± 1.52 | 21.4 ± 2.27 | 14.2 ± 1.04 | 17.44 ± 1.61 | 18.56 ± 0.41 | 16.8 ± 1.46 | 18.2 ± 0.72 | 16.0 ± 1.49 | 17.6 ± 1.50 | 23.78 ± 0.74 | 8.56 ± 0.80 | 19.8 ± 1.58 | 8.6 ± 0.90 | 24.6 ± 1.61 | 8.0 ± 0.88 |
| 10–20 | 20.78 ± 1.10 | 18.44 ± 0.77 | 20.4 ± 1.85 | 13.8 ± 1.55 | 21.2 ± 2.24 | 19.6 ± 0.69 | 18.78 ± 1.91 | 18.33 ± 1.51 | 18.8 ± 1.82 | 19.0 ± 0.53 | 21.0 ± 2.37 | 19.6 ± 0.90 | 21.44 ± 2.19 | 9.22 ± 0.78 | 21.8 ± 2.17 | 9.4 ± 0.69 | 20.0 ± 2.58 | 8.8 ± 0.86 |
| 20–30 | 19.89 ± 1.72 | 18.33 ± 1.42 | 19.6 ± 1.43 | 18.4 ± 1.43 | 20.6 ± 1.54 | 19.6 ± 1.34 | 20.0 ± 1.06 | 21.67 ± 1.47 | 19.8 ± 1.01 | 21.2 ± 1.59 | 21.0 ± 0.85 | 20.8 ± 2.02 | 23.89 ± 1.39 | 8.89 ± 0.74 | 22.8 ± 1.14 | 9.2 ± 0.83 | 24.0 ± 0.71 | 8.2 ± 0.43 |

**Table 13. Results of Analysis of Variance (ANOVA) to Test the Variability in Phosphorus Content due to Mining Activity, Site and Depth**

| *Source of Variation* | *Degree of freedom* | *Sum of squares* | *Mean sum of squares* | *F ratio* |
|---|---|---|---|---|
| General Mean | 1 | 22554.31 | 22554.31 | – |
| Mining effects | 1 | 3.84 | 3.84 | 0.13 |
| Site effects | 2 | 8.09 | 4.05 | 0.14 |
| Depth effects | 2 | 40.93 | 20.46 | 0.71 |
| Mining-Site | 2 | 38.40 | 19.20 | 0.67 |
| Mining-Depth | 2 | 59.68 | 29.84 | 1.03 |
| Site-Depth | 4 | 26.10 | 6.53 | 0.23 |
| Mining-Site-Depth | 4 | 25.65 | 6.41 | 0.22 |
| Residual | 36 | 1039.23 | 28.87 | – |
| Total | 54 | 23796.24 | 440.67 | – |

*wallichii* and *Bauhinia variegata* were dominant trees in the mined sites. *Citrus* sp., *Hiptage benghalensis, Clerodendrum wallichii, Elsholtzia blanda* and *Psychotria erratica* were the dominant shrub species in the unmined areas while in the mined areas *Clerodendrum wallichii, Agapetes variegata, Millitia pachycarpa, Desmodium racemosa, Lantana camara* and *Olea dentana* were dominant. Among the herb species, *Davallia* sp., *Piper longrum* and *Asplenium* sp. were the dominant in unmined areas and in the mined areas *Eupatorium adenophorum, Pteris* sp., *Thysanolaena maxima, Asplenium* sp., *Eleusine corocana* and *Inula cappa* were dominant species. Shannon's diversity index for tree species was low in the mined sites than the unmined sites at Budugiri and Faramgiri. However, at Budu Wathegiri, the trend was reverse. This could be attributed to the existence of bigger trees and causing less damage to the trees during mining operation. The herb species diversity however, increased with mining activity. Unmined sites had better tree regeneration than the mined sites. Most of the tree species showed contagious distribution pattern both at unmined and mined sites. Due to mining, the contagiousness increased. This is in agreement with the findings of Rao *et al.* (1990), who observed that due to disturbance contagiousness increased. Webb *et al.* (1967), Ashton (1972) and Austin *et al.* (1972) indicated that in the absence of major disturbances, soil and water conditions play significant roles in controlling such distribution pattern.



**Table 14. Percentage of Soil Organic Matter in the Unmined and Mined Areas in Different Depths and Seasons in the Nokrek Biosphere Reserve**

| *Depth (cm)* | *Pre-monsoon* | | | | | | *Monsoon* | | | | | | *Post-monsoon* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | |
| | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* |
| 0–10 | 6.17 ± 0.25 | 0.97 ± 0.06 | 5.72 ± 0.35 | 0.95 ± 0.06 | 5.98 ± 0.49 | 0.97 ± 0.06 | 4.89 ± 0.25 | 0.71 ± 0.12 | 4.62 ± 0.32 | 0.44 ± 0.10 | 5.86 ± 0.38 | 0.61 ± 0.16 | 3.52 ± 0.26 | 0.88 ± 0.06 | 3.58 ± 0.21 | 0.89 ± 0.06 | 3.25 ± 0.19 | 0.89 ± 0.07 |
| 10–20 | 5.85 ± 0.38 | 1.26 ± 0.23 | 5.67 ± 0.37 | 1.26 ± 0.23 | 5.86 ± 0.48 | 1.36 ± 0.23 | 4.89 ± 0.19 | 0.91 ± 0.08 | 4.19 ± 0.27 | 1.03 ± 0.10 | 4.377 ± 0.24 | 0.83 ± 0.07 | 2.75 ± 0.13 | 0.91 ± 0.41 | 2.67 ± 0.31 | 0.86 ± 0.06 | 3.03 ± 0.23 | 0.90 ± 0.08 |
| 20–30 | 5.38 ± 0.58 | 1.11 ± 0.10 | 5.02 ± 0.36 | 0.99 ± 0.08 | 5.22 ± 0.34 | 1.15 ± 0.11 | 4.23 ± 0.20 | 1.22 ± 0.14 | 4.35 ± 0.33 | 1.08 ± 0.16 | 3.84 ± 0.18 | 1.26 ± 0.18 | 2.64 ± 0.09 | 1.26 ± 0.17 | 2.60 ± 0.41 | 1.09 ± 0.10 | 2.65 ± 0.41 | 1.23 ± 0.17 |

**Table 15. Results of Analysis of Variance (ANOVA) to Test the Variability in Percentage of Soil Organic Matter Content due to Mining Activity, Site and Depth**

| *Source of Variation* | *Degree of freedom* | *Sum of squares* | *Mean sum of squares* | *F ratio* |
|---|---|---|---|---|
| General Mean | 1 | 399.24 | 399.24 | – |
| Mining effects | 1 | 152.64 | 152.64 | 2203.63** |
| Site effects | 2 | 0.62 | 0.31 | 4.47* |
| Depth effects | 2 | 19.21 | 9.61 | 138.68** |
| Mining-Site | 2 | 3.34 | 1.67 | 24.13** |
| Mining-Depth | 2 | 14.23 | 7.11 | 102.71** |
| Site-Depth | 4 | 0.80 | 0.20 | 2.89* |
| Mining-Site-Depth | 4 | 0.25 | 0.06 | 0.90 |
| Residual | 36 | 2.49 | 0.07 | – |
| Total | 54 | 592.82 | 10.98 | – |

All the soil physico-chemical characteristics were adversely affected due to mining. The soil became more acidic in the mined areas and the soil moisture regime of the soil got depleted. The soil nitrogen and soil organic matter were less in the mined areas than that of unmined areas. The C/N ratio was drastically reduced due to the mining. The deterioration in soil physico-chemical properties would have detrimental effect on the soil flora, fauna and micro-organisms. The impact of mining was felt even upto the depth of 30 cm suggesting that coal mining would adversely affect even the growth of higher plants.

**Table 17. Results of Analysis of Variance (ANOVA) to Test the Variability in percentage of Soil Organic Carbon Content due to Mining Activity, Site and Depth**

| *Source of Variation* | *Degree of freedom* | *Sum of squares* | *Mean sum of squares* | *F ratio* |
|---|---|---|---|---|
| General Mean | 1 | 129.33 | 129.33 | – |
| Mining effects | 1 | 48.34 | 48.34 | 6257.73** |
| Site effects | 2 | 0.03 | 0.02 | 2.19 |
| Depth effects | 2 | 6.53 | 3.26 | 422.49** |
| Mining-Site | 2 | 0.76 | 0.38 | 49.51** |
| Mining – Depth | 2 | 5.54 | 2.77 | 358.87** |
| Site-Depth | 4 | 0.16 | 0.04 | 5.10** |
| Mining-Site-Depth | 4 | 0.09 | 0.02 | 3.07* |
| Residual | 36 | 0.28 | 0.01 | – |
| Total | 54 | 191.07 | 3.54 | – |



**Table 16. Percentage of Soil Organic Carbon in the Unmined and Mined Areas in Different Depths and Seasons in the Nokrek Biosphere Reserve**

| *Depth (cm)* | *Pre-monsoon* | | | | | | *Monsoon* | | | | | | *Post-monsoon* | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | | *Budugiri* | | *Budu Wathegiri* | | *Faramgiri* | |
| | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* | *UM* | *M* |
| 0–10 | 3.50 ± 0.16 | 0.56 ± 0.04 | 3.32 ± 0.28 | 0.56 ± 0.05 | 3.48 ± 0.28 | 0.56 ± 0.05 | 2.87 ± 0.16 | 0.47 ± 0.15 | 2.81 ± 0.20 | 0.36 ± 0.10 | 2.81 ± 0.27 | 0.36 ± 0.10 | 1.95 ± 0.16 | 0.50 ± 0.04 | 1.62 ± 0.23 | 0.52 ± 0.04 | 1.62 ± 0.23 | 0.52 ± 0.04 |
| 10–20 | 3.29 ± 0.24 | 0.78 ± 0.15 | 3.40 ± 0.49 | 0.78 ± 0.15 | 3.4 ± 0.49 | 0.78 ± 0.15 | 2.31 ± 0.08 | 0.45 ± 0.05 | 2.54 ± 0.15 | 0.48 ± 0.04 | 2.54 ± 0.15 | 0.48 ± 0.04 | 1.54 ± 0.08 | 0.56 ± 0.04 | 1.76 ± 0.14 | 0.52 ± 0.05 | 1.76 ± 0.14 | 0.52 ± 0.05 |
| 20–30 | 3.17 ± 0.37 | 0.71 ± 0.08 | 3.03 ± 0.26 | 0.69 ± 0.07 | 3.03 ± 0.20 | 0.69 ± 0.07 | 2.41 ± 0.13 | 0.61 ± 0.09 | 2.23 ± 0.12 | 0.73 ± 0.10 | 2.23 ± 0.14 | 0.73 ± 0.10 | 1.43 ± 0.06 | 0.90 ± 0.10 | 1.64 ± 0.22 | 0.71 ± 0.10 | 1.64 ± 0.22 | 0.71 ± 0.10 |

**Table 18. C/N ratio in the Unmined and Mined Areas in Different Depths and Seasons in the Nokrek Biosphere Reserve**

| Depth (cm) | Pre-monsoon | | | | | | Monsoon | | | | | | Post-monsoon | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Budugiri | | Budu Wathegiri | | Faramgiri | | Budugiri | | Budu Wathegiri | | Faramgiri | | Budugiri | | Budu Wathegiri | | Faramgiri | |
| | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M | UM | M |
| 0–10 | 8.71 ± 0.58 | 4.27 ± 0.34 | 10.67 ± 0.38 | 4.23 ± 0.09 | 8.4 ± 0.28 | 3.72 ± 0.46 | 2.84 ± 0.19 | 10.23 ± 2.70 | 4.74 ± 0.24 | 3.69 ± 0.92 | 4.55 ± 0.18 | 9.83 ± 2.26 | 3.45 ± 0.24 | 6.44 ± 0.25 | 3.58 ± 0.39 | 5.90 ± 0.26 | 3.13 ± 0.16 | 5.33 ± 0.48 |
| 10–20 | 10.37 ± 0.32 | 7.22 ± 1.02 | 17.04 ± 2.14 | 7.65 ± 1.69 | 19.11 ± 2.67 | 7.9 ± 0.74 | 2.53 ± 0.01 | 4.07 ± 0.22 | 3.86 ± 0.07 | 3.27 ± 0.09 | 4.56 ± 0.37 | 4.54 ± 0.56 | 2.87 ± 0.01 | 4.70 ± 0.25 | 3.27 ± 0.18 | 5.58 ± 0.45 | 3.16 ± 0.09 | 4.97 ± 0.41 |
| 20–30 | 7.09 ± 0.80 | 6.26 ± 0.43 | 8.72 ± 0.37 | 5.67 ± 0.29 | 9.57 ± 0.47 | 6.29 ± 0.60 | 2.4 ± 0.05 | 5.46 ± 0.48 | 4.07 ± 0.22 | 4.22 ± 0.19 | 3.78 ± 0.27 | 4.94 ± 0.60 | 2.33 ± 0.05 | 6.12 ± 0.20 | 3.41 ± 0.62 | 4.89 ± 0.43 | 3.10 ± 0.47 | 8.54 ± 0.92 |



**Table 19. Results of Analysis of Variance (ANOVA) to Test the Variability in C/N Ratio due to Mining Activity, Site and Depth**

| *Source of Variation* | *Degree of freedom* | *Sum of squares* | *Mean sum of squares* | *F ratio* |
|---|---|---|---|---|
| General Mean | 1 | 1863.73 | 1863.73 | 0.21 |
| Mining effects | 1 | 0.54 | 0.54 | 2.21 |
| Site effects | 2 | 11.25 | 5.62 | 36.39** |
| Depth effects | 2 | 185.43 | 92.71 | 3.82* |
| Mining-Site | 2 | 19.47 | 9.73 | 32.93** |
| Mining-Depth | 2 | 167.79 | 83.90 | 8.99** |
| Site-Depth | 4 | 91.66 | 22.92 | 1.51 |
| Mining-Site-Depth | 4 | 15.36 | 3.84 | – |
| Residual | 36 | 91.71 | 2.55 | – |
| Total | 54 | 2446.93 | 45.31 | – |

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